Competition of electron capture and beta-decay rates in supernova collapse

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We calculate supernova electron capture and β decay rates for various pf-shell nuclei using large-scale shell model techniques. We show that the centroid of the Gamow-Teller strength distribution has been systematically misplaced in previous rate estimates. Our total electron capture rates are significantly smaller than currently adopted in core collapse calculations, while the total β decay rates change less. Our calculation shows that for electron-to-baryon ratios $Y_e = 0.42$-0.46 β decay rates are larger than the competing electron capture rates.

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I. INTRODUCTION

Weak interaction processes play a decisive role in the early stage of the core collapse of a massive star [1,2]. First, electron capture on nuclei in the iron mass region, starting after the core mass exceeds the appropriate Chandrasekhar mass limit, reduces the electron pressure, thus accelerating the collapse, and lowers the electron-to-baryon ratio, Y_e, thus shifting the distribution of nuclei present in the core to more neutron-rich material. Second, many of the nuclei present can also β decay. While this process is quite unimportant compared to electron capture for initial Y_e values around 0.5, it becomes increasingly competative for neutron-rich nuclei due to an increase in phase space related to larger Q_β values. However, β decay on nuclei with masses $A > 60$ have not yet been considered in core collapse studies [3]. This is surprising since Gerry Brown pointed out nearly a decade ago [4] that certain nuclei heavier than $A = 60$, like ^{63}Co and ^{64}Co, have very strong β-decay matrix elements making it conceivable that they can actually compete with electron capture. Brown argued that this might have quite interesting consequences for the collapse. During this early stage of the collapse, neutrinos produced in both electron capture and β decay still leave the star. Therefore, a strong β-decay rate will cool the star without lowering the Y_e value. As a consequence, the Y_e value at the formation of the homologous core (after neutrino trapping) might be larger than assumed. This results in a smaller envelope, and less energy is required for the shock to travel through the material.

Following Brown's suggestion, β decay rates for nuclei in the mass range $A = 48 - 70$ were investigated [5]. These studies were based on the same strategy and formalism as already employed by the pioneering work in this field by Fuller, Fowler and Newman (commonly abbreviated by FFN) [6]. The important idea in FFN was to recognize the role played by the Gamow-Teller resonance in β decay. Other than in the laboratory, β decay rates under stellar conditions are significantly increased due to thermal population of the Gamow-Teller back resonance in the parent nucleus (the GT back resonance are the states reached by the strong GT transitions in the inverse process (electron capture) built on the ground and excited states, see [6,5]) allowing for a transition with a large nuclear matrix element and increased phase space. Indeed, Fuller et al. concluded that the β decay rates under collapse conditions is dominated by the decay of the back resonance. In a more recent work, Aufderheide et al. came to the same conclusion. Inspired by the independent particle model, the authors of Ref. [5] estimated the β decay rates in a similar fashion as the electron capture rates, and phenomenologically parametrized the position and the strength of the back resonance. This estimate was supplemented by an empirical contribution, placed at zero excitation energy, which simulates low-lying transition strength missed by the GT resonance.

When extending the FFN rates to nuclei with $A > 60$, Aufderheide et al. found indeed that the β decay rates are strong enough to balance the electron capture rates for $Y_e \approx 0.42 - 0.46$. Nevertheless, these results have never been explored in details in core collapse calculations.

In recent years the parametrization of the electron capture and β decay rates as adopted by FFN and Aufderheide et al. have become questionable due to experimental data [7–11] and have been critizised on the basis of more elaborate theoretical models [12–15]. We will show in this paper, that although the previous weak interaction rates for core collapse are systematically incorrect, the important observation that electron and β decay rates balance each other for a certain range of Y_e values is indeed correct. Our conclusions will be based on large-scale shell model calculations for several key nuclei which, due to Aufderheide et al. [5], contribute most significantly to the electron capture and β decay rates at various stages of the collapse. These shell model calculations reproduce the measured GT strength distributions for nuclei in the mass range $A = 50 - 64$ very well [16]. Furthermore modern large-scale shell model calculations

also agree with measured half-lifes very well. Thus for the first time one has a tool in hand which allows for a reliable calculation of presupernova electron capture and β decay rates. Modern shell model calculations come in two varieties: large-scale diagonalization approaches [17] and shell model Monte Carlo (SMMC) techniques [18,19]. The latter can treat the even larger model spaces, but has limitations in its applicability to odd-A and odd-odd nuclei at low temperatures, which does not apply to the former. More importantly the diagonalization approach allows for detailed spectroscopy, while the SMMC model yields only an "averaged" GT strength distribution which introduces some inaccuracy into the calculation of the capture and decay rates.

We will consistenly use in the following the shell model diagonalization approach to study these rates. Due to the very large m-scheme dimensions involved, the GT strength distributions have been calculated in truncated model spaces which fulfill the Ikeda sum rule. However, at the chosen level of truncation involving typically 10 million configurations or more, the GT strength distribution is virtually converged. As residual interaction we adopted the recently modified version of the KB3 interaction which corrects the slight inefficiencies in the KB3 interaction around the $N = 28$ subshell closure [20]. In fact the modified KB3 interaction i) reproduces all measured GT strength distributions very well and ii) describes the experimental level spectrum of the nuclei studied here quite accurately [16,20]. As $0\hbar\omega$ shell model calculations, i.e. calculations performed in one major shell, overestimate the experimental GT strength by a universal factor [21–23], we have scaled our GT strength distribution by this factor, $(0.74)^2$.

Large-scale shell model calculations of the electron capture rates for key nuclei in the presupernova collapse have been reported already elsewhere [14,15]; see also the SMMC results in [13]. In these studies it became apparent that the phenomenological parametrization of the GT contribution to the electron capture and β decay rates, as introduced in FFN [6] and subsequently used by Aufderheide et al. [5], is systematically incorrect. These authors have placed the centroid of the GT strength distribution at too high an excitation energy in the daughter nucleus for electron capture on even-even nuclei, while for capture on odd-A and odd-odd nuclei they underestimated the energy of the GT centroid noticeably. For capture on even-even nuclei this has comparably little effect as FFN overcompensate the misplacement of the GT centroid by a too large empirical contribution at zero excitation energy. Typically the FFN rates are roughly a factor of 5 larger than the shell model rates for capture on even-even nuclei like ^{56,58}Ni or ^{58}Fe. For capture on odd-odd and odd-A nuclei the misplacement of the GT centroid makes the FFN rates about 1-2 orders of magnitude too large compared to the shell model rates. As a consequence, FFN and Aufderheide et al. have noticeably overestimated the electron capture rates for the early stage of the supernova collapse.

Which consequences do the misplacement of the GT centroids have for the competing β decays? In odd-A and even-even nuclei (the daughters of electron capture on odd-odd nuclei), experimental data and shell model studies place the back-resonance at higher excitation energies than assumed by FFN and Aufderheide et al. [5]. Correspondingly, its population becomes less likely at the temperatures available during the early stage of the collapse ($T_9 \approx 5$, where T_9 measures the temperature in 10^9 K) and hence the contribution of the back-resonance to the β decay rates for even-even and odd-A nuclei decreases. Due to Aufderheide et al. [5], some of the most important β decay nuclei (defined by the product of abundance and β decay rate and listed in Tables 18-22 in [5]) are odd-odd nuclei. For these nuclei, all available data, stemming from (n,p) reaction cross section measurements on even-even nuclei like ^{54,56,58}Fe or ^{58,60,62,64}Ni, and all shell model calculations indicate that the back-resonance resides actually at lower excitation energies than previously parametrized. Consequently, the contribution of the back-resonance to the β decay rate of odd-odd parent nuclei should be larger than assumed in the compilations. We note that this general expectation has already been conjectured in Ref. [12] on the basis of (n,p) data available at that time. These authors have attempted to fit the data within a strongly truncated shell model calculation which then in turn has been used to predict a corresponding β decay rate. This procedure is viewed as rather uncertain as i) the large energy resolution in the data made its convolution into a β decay rate imprecise and ii) the shell model truncation level was too inaccurate in order to estimate reliably the contribution of other states than the back-resonance to the decay rate. These shortcomings can be overcome in recent state-of-the-art large scale shell model calculations. We have calculated the β decay rates for several nuclei under relevant core collapse conditions ($\rho_7 = 10 - 1000$, where ρ_7 measures the density in 10^7 g/cm^3 and temperatures $T_9 = 1 - 10$). These nuclei include even-even ones (^{52}Ti,^{54}Cr, ^{56,58,60}Fe), odd-A nuclei (^{59}Mn, ^{59,61}Fe, ^{61,63}Co) and odd-odd nuclei (^{50}Sc,^{54,56}Mn, ^{58,60}Co). The selection has been made to include those nuclei which have been ranked as most important for core collapse simulations by Aufderheide et al. [5]. In fact, with the rates of Ref. [5] these 15 nuclei contribute between 65% and 86% to the change of Y_e due to β decay in the range $Y_e = 0.44 - 0.47$.

Although the formula for the presupernova β decay rate λ_β is well known (e.g. [6,5]), we have chosen to quote the basic result here as this allows for the easiest discussion of the improvement incorporated in our calculation compared to previous work. Thus,

$$\lambda_\beta = \frac{\ln 2}{6163\text{sec}} \sum_{ij} \frac{(2J_i+1)\exp\left[-E_i/kT\right]}{G} S_{\text{GT}}^{ij} \frac{c^3}{(m_e c^2)^5} \int_0^{\mathcal{L}} dp p^2 (Q_{ij} - E_e)^2 \frac{F(Z+1, E_e)}{1+\exp\left[kT(\mu_e - E_e)\right]} \,, \tag{1}$$

where E_e, p, and μ_e are the electron energy, momentum, and chemical potential, and $\mathcal{L} = (Q_{if}^2 - m_e^2 c^4)^{1/2}$; $Q_{if} = E_i - E_f$ is the nuclear energy difference between the initial and final states, while $S_{\rm GT}^{ij}$ is their GT transition strength. Z is the charge number of the parent nucleus, G is the partition function, $G = \sum_i (2J_i+1)\exp[-E_i/kT]$, while F is the Fermi function which accounts for the distortion of the electron's wave function due to the Coulomb field of the nucleus. The values for the chemical potential are taken from [13].

To estimate the rates at finite temperatures, the compilations employed the so-called Brink hypothesis [5,24] which assumes that the GT strength distribution on excited states is the same as for the ground state, only shifted by the excitation energy of the state. We have not used this approximation, but have performed shell model calculations for the individual transitions. Our sum over initial states includes i) explicitly the ground state and several excited states in the parent nucleus (usually at least all levels below 1 MeV excitation energy) and ii) all back-resonances which can be reached from the levels in the daughter nucleus below 1 MeV excitation energy. As these back-resonances also include parent states below 1 MeV, special care has been taken in avoiding double-counting. The partition function is consistenly summed over the same initial states.

Here a word of caution is in order. We have calculated the GT strength distributions using 33 Lanczos iterations in all allowed angular momentum and isospin channels. This is usually sufficient to converge in the states at excitation energies below $E = 3$ MeV. At higher excitation energies, $E > 3$ MeV, the calculated GT strengths represent centroids of strengths, which in reality are split over many states. While this does not introduce uncertainties in the summing over the GT strengths (the numerator in (1)), it might be inconsistent for the calculation of the partition function. However, this is practically not the case, as at the rather low temperatures of concern here the partition function is given by those states which have already converged in our model space. Nevertheless there might be states outside of our model space (intruder states) which will be missed in our evaluation of the β decay rates. But their statistical weight in both numerator and denominator in the rate equation (1) is small. Although our calculations agree well with the experimental informations available (excitation energies and GT transition strengths), we have replaced the shell model results by data whenever available.

In Fig. 1 we compare our shell model β decay rates with those of FFN for selected nuclei representing the three distinct classes: even-even (^{54}Cr, ^{56,60}Fe), odd-A (^{59}Mn, ^{57,59}Fe) and odd-odd (^{54,56}Mn, ^{58}Co). We note again that β decay of the nuclei studied here is important at temperatures $T_9 \le 5$ [5]. For the odd-odd nuclei we calculate rates similar to those of FFN. This approximate agreement is, however, somewhat fortunate. In FFN the misplacement of the GT back-resonances has been compensated by too large values for the total GT strengths (FFN adopted the unquenched single particle estimate) and the low-lying strengths. At higher temperatures ($T_9 > 5$), the FFN rates for odd-odd nuclei are larger than our shell model rates. For odd-A and even-even nuclei our shell model rates are significantly smaller than the FFN rates as the back resonance, for $T_9 < 5$, is less populated thermally than in the FFN parametrization. Using the FFN rates, even-even nuclei were found to be unimportant for β decay in the core collapse; our lower rates make them even less important. This situation is somewhat different for odd-A nuclei which (^{57,59}Fe, ^{59}Mn) have been identified as important in Ref. [5] adopting the FFN rate. Aufderheide et al. have added several odd-A nuclei with masses $A > 60$ (which are not calculated in FFN) to the list of those nuclei which significantly change the Y_e value during the collapse by β decays. These nuclei include ^{61}Fe and ^{61,63}Co; we will show below that their rates have also been overestimated significantly in Ref. [5]. Our shell model rates indicate that the importance of odd-A nuclei is significantly overestimated when the previously compiled values are adopted.

In Ref. [12] β decay rates for several nuclei have been estimated in strongly truncated shell model calculations, in which these authors allowed a maximum of 1 nucleon to be excited from the $f_{7/2}$ shell to the rest of the pf-shell in the daughter nucleus, and fitted the single particle energy spectra to reproduce measured (n,p) data for ^{54,56}Fe, ^{58}Ni and ^{59}Co; the (n,p) data constrain the back-resonance transition to the ground states in the β decays of ^{54,56}Mn, ^{58}Co and ^{59}Fe. Our shell model rates are compared to the estimates of Ref. [12] in Fig. 2. For the 3 odd-odd nuclei, the agreement is usually better than a factor 2. This is due to the fact that these rates are dominated by the back-resonances, i.e. the (n,p) data of the daughter nucleus, which are reproduced in our large-scale shell model approach and have been fitted in Ref. [12]. For the odd-A nucleus ^{59}Fe our β decay rate is about an order of magnitude lower than the estimate of Ref. [12] at $T_9 = 2$, while the rates agree for $T_9 > 6$, where it is dominated by the back-resonances. At the lower temperatures, β decays of low-lying states are important which might be overestimated in the truncated calculation.

What might the revised β decay rates mean for the core collapse? To investigate this question we study the change of the electron-to-baryon ratio, $\dot{Y}_e$, along a stellar trajectory. Following Ref. [5], we define

$$Y_e = \sum_k \frac{Z_k}{A_k} X_k \tag{2}$$

where the sum runs over all nuclear species present in the core. Z, A, and X are the charge, mass number, and mass fraction of the nucleus, respectively. The mass fraction is given by nuclear statistical equilibrium [5]; we will use the values as given in Tables 14-24 of Ref. [5]. Noting that β decay (β) increases the charge by one unit, while electron capture (ec) reduces it by one unit, we have

$$\dot{Y}_e^{ec(\beta)} = \frac{dY_e^{ec(\beta)}}{dt} = -(+) \sum_k \frac{X_k}{A_k} \lambda_k^{ec(\beta)} \quad (3)$$

where λ_k^{ec} and λ_k^{β} are the electron capture and β decay rates of nucleus k. For several key nuclei we have calculated these rates within large-scale shell model studies. Some of the results are listed in Tables 1 and 2, where they are also compared to the FFN rates and the ones of Ref. [5]. This comparison also includes the β decay rates for ^{61}Fe and ^{61,63}Co, which, due to [5] and earlier suggested by Brown [4,25], are important when the stellar trajectory reaches electron-to-baryon values $Y_e = 0.44 - 0.46$. Our shell model rates agree for ^{63}Co with the rate of Aufderheide et al., but are smaller than the estimates of these authors by factors 2 and 5 for ^{61}Fe and ^{61}Co, respectively. We note that the strong ground state decay of ^{63}Co contributes about 15% to the total rate at the condition listed in Table 2. Some of the electron capture rates are taken from [14,15], while several other shell model rates are presented here for the first time (e.g. for ^{54,56}Fe, ^{58}Ni and the odd-A nuclei). Although the nuclei, for which reliable shell model rates are now available, include the dominant ones at the various stages of the early collapse (due to the ratings in Ref. [5]), there are upto 250 nuclei present in NSE at higher densities [5]. Although we are currently working at a revised compilation for β decay and electron capture rates for nuclei in the mass range $A = 45 - 65$, its completion is computer-intensive and tedious. Nevertheless some important conclusions can already be drawn from the currently available data.

At first we will follow the stellar trajectory as given in Ref. [5], although some comments about this choice are given below. We estimated $\dot{Y}_e^{ec}$ and $\dot{Y}_e^{\beta}$ separately on the basis of the 25 most important nuclei listed in Tables 14-24 in [5]. We used shell model rates for the nuclei listed in Table 1 and 2. For the other nuclei we scaled the FFN rates using the following scheme which corrects for the systematic misplacement of the GT centroid and is derived by the comparison of FFN and shell model rates for the nuclei listed in Tables 1 and 2. The FFN electron capture rates have been multiplied by 0.2 (even-even), 0.1 (odd-A) and 0.04 (odd-odd), while the FFN β decay rates have been scaled by 0.05 (even-even), 0.025 (odd-A) and 1.5 (odd-odd). The results for $\dot{Y}_e^{ec,\beta}$ are plotted in Fig. 3, where they are also compared to the values obtained for the FFN rates. One observes that the shell model rates reduce $\dot{Y}_e^{ec}$ significantly, by more than an order of magnitude for $Y_e < 0.47$. This is due to the fact, that, except for ^{56}Ni, all shell model electron capture rates are smaller than the recommendations given in the FFN and Aufderheide et al. compilations [6,5]. In particular, this is drastic for capture on odd-odd nuclei, which due to these compilations, dominate $\dot{Y}_e^{ec}$ at densities $\rho_7 > 10$. The shell model β decay rates also reduce $\dot{Y}_e^{\beta}$, however, by a smaller amount than for electron capture. This is mainly caused by the fact that the shell model β decay rates of odd-odd nuclei are about the same as the FFN rates or even slightly larger, for reasons discussed above.

It is interesting to note that FFN typically give higher β-decay rates for odd-A nuclei than Aufderheide et al. [5], while it is vice versa for odd-odd nuclei. As a consequence $\dot{Y}_e^{\beta}$ is dominated by odd-A nuclei for $Y_e < 0.46$ if the FFN rates are used, while odd-odd nuclei contribute significantly if the rates of [5] are adopted. In either case, both compilations yield rather similar profiles for $\dot{Y}_e^{ec,\beta}$ (see Fig. 14 in [5]). The important feature in Fig. 3 is the fact that the β decay rates are larger than the electron capture rates for $Y_e = 0.42 - 0.455$, which is also already true for the FFN rates [5].

So far we have used the same stellar trajectory as in Ref. [5]. This allowed a comparison with the conclusions obtained in that reference. However, this assumption is inconsistent, and, in fact, was already inconsistent in [5]. The chosen stellar trajectory is based on runs performed with the stellar evolution code KEPLER [26] which uses the FFN electron capture rates, but quite outdated β decay rates [27], following the old belief that β decay rates are unimportant [27]. The outdated β decay rates were derived basically from a statistical model approach [28] and are orders of magnitude too small [4]. What are the consequences and will electron capture and β decay rate also balance in a consistent model? At the beginning of the collapse, electron capture is significantly faster than β decay (see Fig. 3). The shell model rates make ^{56}Ni the most important contributor, but it cannot quite compensate for the reduction of the ^{55}Co rate. Thus, at $Y_e = 0.485$ the total electron capture rate $\dot{Y}_e^{ec}$ drops slightly. This reduction is more severe for smaller Y_e values, until at $Y_e = 0.46$ electron capture and β decay balance. The consequence is that, due to the slower electron capture, the star radiates less energy away in form of neutrinos until $Y_e = 0.46$ is reached. Thus one expects that in the early stage the stellar trajectory is, for a given density, at a higher temperature. This, of course, increases both the β decay and electron capture rates. Importantly both rates have roughly the same temperature dependence in the relevant temperature range: typically electron capture rates are enhanced by an order of magnitude if the temperature raises from $T_9 = 4$ to $T_9 = 6$. But this increase is the same order of magnitude by which the β decay rates grow in the same temperature interval. Consequently the two rates will also be balanced at around $Y_e \approx 0.46$ if a consistent stellar trajectory is used.

As stated above, the dominance of β decay over electron capture during a certain stage of the core collapse of a massive star has been suggested or noted before [4,5,27,12]. However, previous argumentation has been based on rates for these two processes which had been empirically and intuitively parametrized, rather than derived from a reliable many-body model. Moreover, it was shown in recent years that the assumed parametrizations, mainly with respect to the energy of the Gamow-Teller

centroid, were systematically incorrect. Shell model calculations are now at hand which allow, for the first time, the reliable calculation of these rates under stellar conditions. Given the fact that the large-scale shell model studies reproduce all important ingredients (spectra, half-lives, GT strength distributions) very well, the shell model rates are rather reliable. We stress an important point, that the shell model β decay rates are larger than the electron capture rates for $Y_e \approx 0.42-0.455$. This might have important consequences for the core collapse. A first investigation into these consequences has been performed by Aufderheide et al. [27], however, using the FFN values for both rates. They find that the competition of β decay and electron capture leads to cooler cores and larger Y_e values at the formation of the homologuous core. These results are important motivation enough to derive a complete set of shell model rates and then use them in core collapse calculations.

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TABLE I. Electron capture rates for selected even-even, odd-A and odd-odd nuclei. The chosen stellar conditions reflect those at which the nuclei are considered to be most important due to the ranking given by Aufderheide et al. [5]. The shell model rates (labelled SM) are compared to those recommended by FFN [6] and Ref. [5]. The last column, named importance ratio, gives the percentage of the total change in $\dot{Y}_e$ (for the definition see text) assigned to the respective nucleus by Aufderheide et al. at the respective stellar conditions. All rates are in s^{-1}. Exponents are given in parentheses.

nucleus	ρ_7	T_9	SM	FFN	Ref. [5]	importance ratio
^{56}Ni	4.32	3.26	1.3 (-2)	7.4 (-3)	8.6 (-3)	0.254
^{54}Fe	5.86	3.40	4.2 (-5)	2.9 (-4)	3.1 (-4)	0.126
^{58}Ni	5.86	3.40	8.1 (-5)	3.7 (-4)	6.3 (-4)	0.065
^{56}Fe	10.7	3.65	2.1 (-6)	1.0 (-5)	4.7 (-7)	0.005
^{55}Co	4.32	3.26	1.6 (-3)	8.4 (-2)	5.1 (-2)	0.501
^{57}Co	5.86	3.40	1.3 (-4)	1.9 (-3)	3.4 (-3)	0.246
^{55}Fe	5.86	3.40	1.9 (-4)	5.8 (-3)	3.8 (-3)	0.126
^{59}Ni	5.86	3.40	4.7 (-4)	4.4 (-3)	4.4 (-3)	0.041
^{59}Co	10.7	3.65	7.8 (-6)	2.1 (-4)	2.1 (-4)	0.151
^{53}Mn	10.7	3.65	3.3 (-4)	3.8 (-3)	5.6 (-3)	0.097
^{56}Co	5.86	3.40	1.7 (-3)	6.9 (-2)	5.1 (-2)	0.074
^{54}Mn	10.7	3.65	3.1 (-4)	4.5 (-3)	1.1 (-2)	0.188
^{58}Co	10.7	3.65	3.5 (-4)	9.1 (-3)	2.1 (-2)	0.057
^{56}Mn	33.0	4.24	1.0 (-4)	4.1 (-4)	2.0 (-3)	0.058
^{60}Co	33.0	4.24	1.7 (-4)	1.1 (-1)	6.1 (-2)	0.513

TABLE II. β decay rates for selected even-even, odd-A and odd-odd nuclei. The chosen stellar conditions reflect those at which the nuclei are considered to be most important due to the ranking given by Aufderheide et al. [5]. The shell model rates (labelled SM) are compared to those recommended by FFN [6] and in Ref. [5]. The last column, labelled importance ratio, gives the percentage of the total change in $\dot{Y}_e$ (for the definition see text) assigned to the respective nucleus by Aufderheide et al. at the respective stellar conditions. All rates are in s^{-1}. Exponents are given in parentheses. FFN did not give rates for nuclei with $A > 60$.

nucleus	ρ_7	T_9	SM	FFN	Ref. [5]	importance ratio
^{56}Fe	5.86	3.40	3.9 (-11)	2.3 (-10)	5.9 (-11)	0.006
^{54}Cr	5.86	3.40	2.2 (-7)	2.2 (-5)	1.5 (-7)	0.032
^{58}Fe	10.7	3.65	5.2 (-8)	2.6 (-6)	1.5 (-7)	0.004
^{60}Fe	33.0	4.24	1.7 (-4)	4.6 (-3)	1.0 (-3)	0.112
^{52}Ti	33.0	4.24	1.3 (-3)	1.1 (-2)	1.2 (-4)	0.001
^{59}Fe	33.0	4.24	6.0 (-5)	6.3 (-3)	5.3 (-3)	0.245
^{61}Fe	33.0	4.24	1.7 (-3)		6.4 (-2)	0.126
^{61}Co	33.0	4.24	1.6 (-4)		9.3 (-4)	0.029
^{63}Co	33.0	4.24	1.6 (-2)		1.4 (-2)	0.057
^{59}Mn	220	5.39	2.2 (-2)	7.2 (-1)	1.4 (-1)	0.095
^{58}Co	4.32	3.26	2.7 (-6)	1.2 (-6)	3.8 (-6)	0.096
^{54}Mn	5.86	3.40	2.7 (-6)	1.6 (-6)	7.5 (-6)	0.320
^{56}Mn	10.7	3.65	3.4 (-3)	3.0 (-3)	9.1 (-3)	0.235
^{60}Co	10.7	3.65	6.6 (-4)	1.4 (-3)	3.4 (-3)	0.116
^{50}Sc	33.0	4.24	1.2 (-2)	2.8 (-2)	1.8 (-1)	0.025

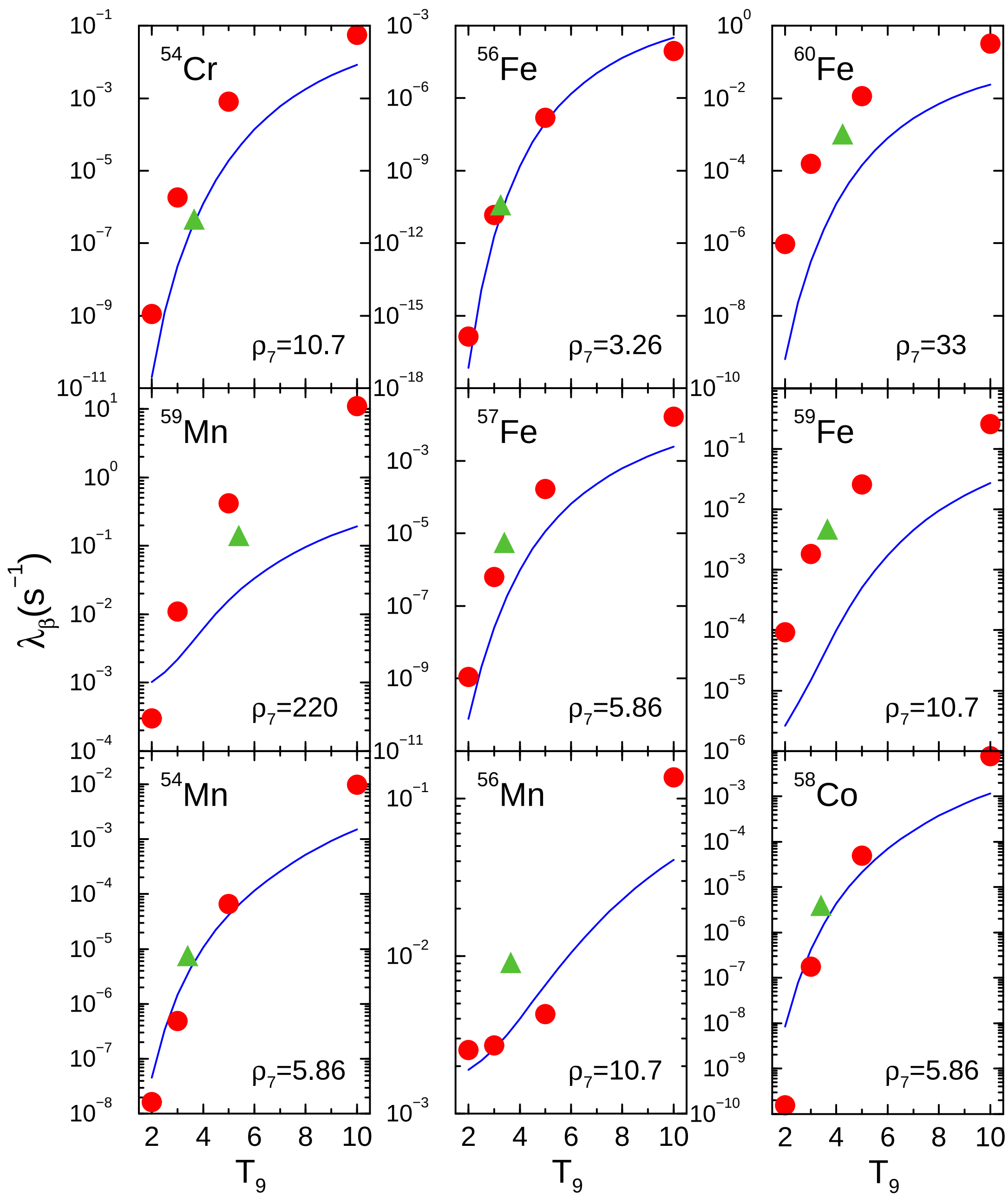

FIG. 1. β decay rates for several nuclei as a function of temperature and at selected densities at which these nuclei are important for electron capture in the presupernova core collapse as suggested by Ref. [5]. The top (middle, bottom) row contains even-even (odd-A, odd-odd) nuclei. The solid line shows the present shell model results, the dots give the FFN rates [6], while the triangles are rates taken from Tables 15-17 in [5].

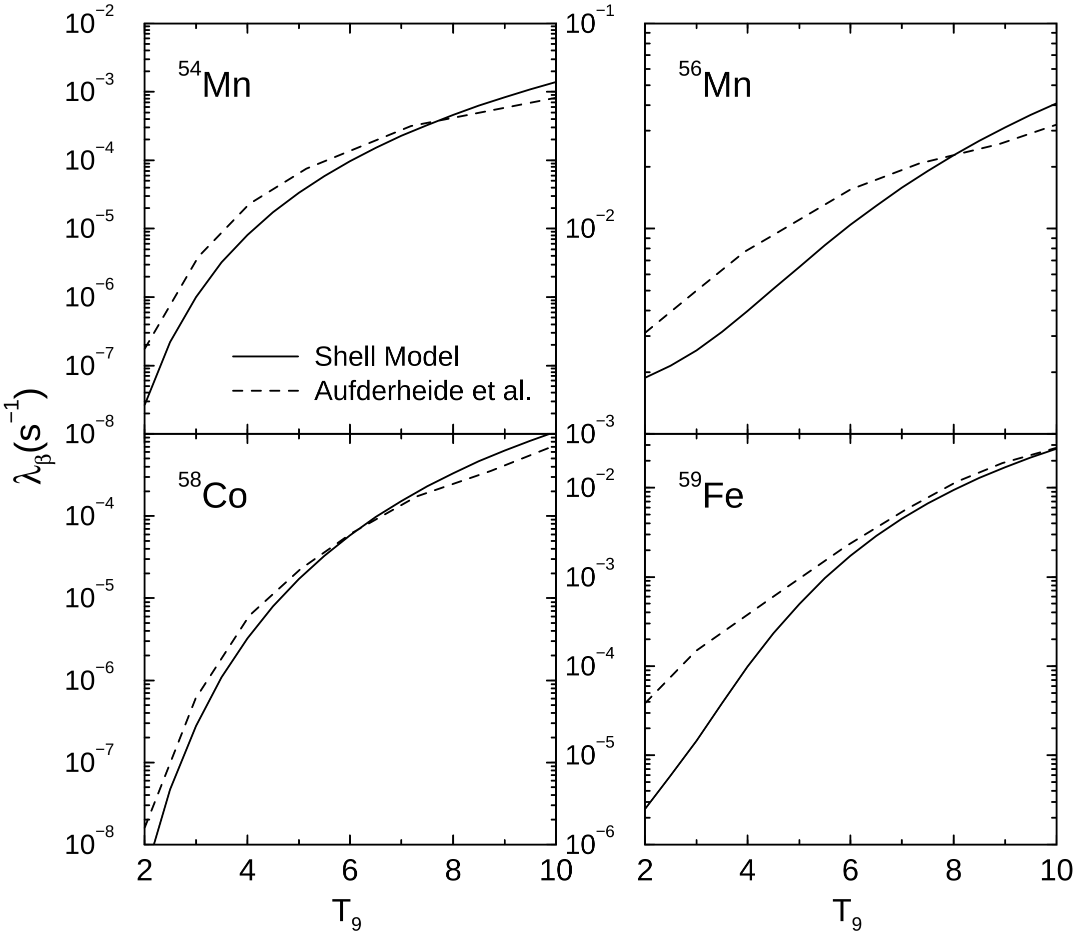

FIG. 2. Comparison of the present shell model rates for ^{54,56}Mn, ^{58}Co and ^{59}Fe (solid line) with those derived in Ref. [12] (dashed line).

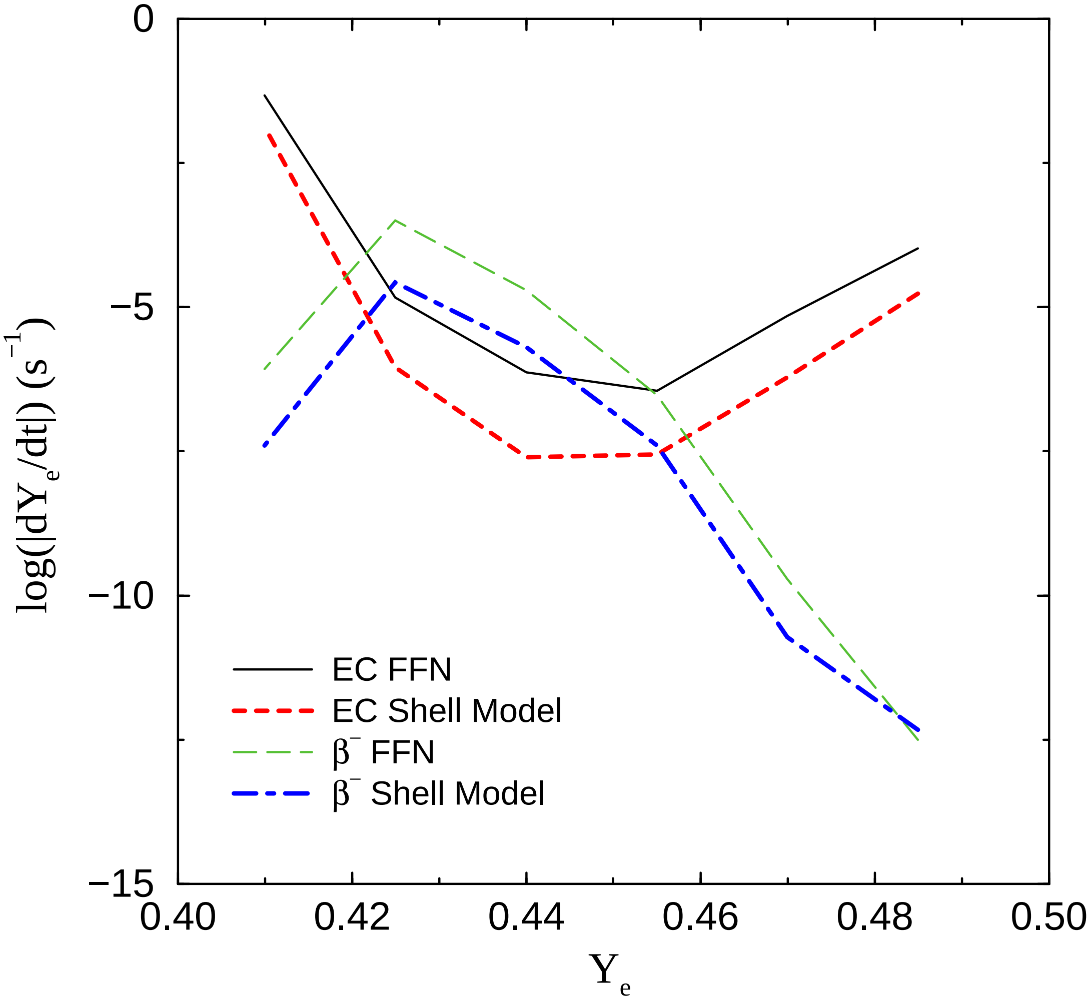

FIG. 3. Change in the total electron capture and β decay rates, $\dot{Y}_e^{ec}$ and $\dot{Y}_e^{\beta}$, respectively. The shell model results are compared with the FFN results along the same stellar trajectory as in Fig. 14 of Ref. [5].